

# Annotated checklist of arthropod-pathogenic species in the Entomophthoromycotina (Fungi, Zoopagomycota) in North America

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## Abstract

The subphylum Entomophthoromycotina (Phylum Zoopagomycota) includes many arthropod pathogens, some of which are renowned for their abilities to alter host behavior prior to death and cause epizootics that impact host populations. The last checklist of arthropod-pathogenic species in this group was published in 1963 and consisted of 39 species in a single genus. Since then, more species have been named, and their taxonomy has changed extensively. We have constructed an updated checklist for species of Entomophthoromycotina in North America; this checklist includes species in the continental United States, Canada, and Mexico. Data were compiled based on available published literature and metadata available from the ARSEF culture collection, adjusting names based on current taxonomy. In North America, the arthropod-pathogenic Entomophthoromycotina now include 80 species belonging to 14 genera, within two classes, plus one species in a form genus. This checklist provides a current framework for future studies of the biodiversity of this group of fungi.

**Key words:** Biodiversity, entomopathogenic fungi, Entomophthorales, mycodiversity, pathogen species list

## Introduction

Most species in the fungal subphylum Entomophthoromycotina (Phylum Zoopagomycota; Spatafora et al. 2016) are pathogens of arthropods. Many species in this group naturally cause epizootics (Pell et al. 2001), highlighting their potential use for biological control of arthropod pests. Species in this group are also renowned for altering the behavior of infected arthropod hosts in fixed, predictable patterns (de Bekker et al. 2021), including ‘summit behavior’ just prior to host death (e.g., Elya et al. 2018) or producing psychoactive metabolites to stimulate continued flight by spore-ejecting infected cicada hosts (Boyce et al. 2019).

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Despite their promising roles in the control of insect pests and their fascinating biology, relatively few studies have documented the biodiversity, distribution, and ecology of entomophthoralean fungi in natural ecosystems. Most inventories of species of arthropod-pathogenic fungi in the Entomophthoromycotina originate from Europe. Twenty-six species have been listed for Spain (Niell and Santamaria 2001), 24 for Sweden (Gustafsson 1965), 12 for Norway (Klingen et al. 2002), 29 for Austria (Barta et al. 2005; Tkaczuk et al. 2011), and 35 for the United Kingdom ([www.mapmate.co.uk/checklist](http://www.mapmate.co.uk/checklist)). The much higher counts for Switzerland (95; Keller 2008; S. Keller pers. comm.) and Poland (94; Sosnowska et al. 2004; Mułenko et al. 2008; Dubiel 2016) are consistent with the suggestion that this group of fungi is most diverse in central Europe (Keller 2008). However, this statement might be biased by the prolific work of researchers specifically studying the subject in that geographical area. Outside of Europe, lists of species have also been reported for China (79; Zha et al. 2016), Israel (31; Ben-Ze'ev 1993), the Philippines (19; Villacarlos and Mejia 2004; Villacarlos 2008), Argentina (16; López Lastra et al. 2019), and Australia (10; Glare and Milner 1987), as well as in several different publications from Mexico (Remaudière and Latgé 1985; Sanchez-Peña 1990, 2000).

For North America, Roland Thaxter published a comprehensive monograph on the family Entomophthoraceae in the United States in 1888, in which he reported on 26 species (Thaxter 1888). Following this, Charles (1941) reported 36 species in this group for North America, and in 1963, Hutchison reported 39 species of entomophthoralean fungi that occurred in North, Central, and South America and provided information about hosts and geographic distributions of these species. In the 21<sup>st</sup> century, a protochecklist of all nonlichenized fungi in North America included 38 species of arthropod-pathogens in the Entomophthoromycotina (Bates and Miller 2018). The protochecklist entries were based on herbarium specimens from the US (plus its territories), Canada, and Mexico, and in many instances, the names of arthropod pathogens that were included are not the currently accepted names.

Although there has not been an up-to-date summary of arthropod pathogens in North American species after 1963, the discovery, taxonomic changes, and research since that time have been prolific. It is very clear that an updated checklist is sorely needed; for example, the most recent protochecklist for all North American fungi does not use current taxonomic genera and species designations for this group (Bates and Miller 2018), certainly because this information might not be easy to find. Therefore, our goal with this annotated checklist was to present arthropod hosts and distributions for arthropod-pathogenic species in the Entomophthoromycotina that occur in North America, using the currently accepted taxonomy. This will facilitate continued progress in this field and summarize disparate observations as a compendium.

## Materials and methods

### Study area

This checklist of arthropod-pathogenic North American species includes records from the continental United States, Canada, and Mexico.

## The data

Published records that were used to begin generating this checklist were found in Thaxter (1888), Charles (1941), Hutchison (1963), and Bałazy (1993). The catalogue of the USDA Agricultural Research Service Collection of Entomopathogenic Fungi (ARSEF 2020) was also used to search for North American records falling within the arthropod-pathogenic Entomophthoromycotina. Subsequently, search engines were used to explore records for additional North American species, using a recent worldwide list of species within the arthropod pathogens of the Entomophthoromycotina (Sacco and Hajek 2023). Personal communication records for R.A. Humber are from his notes regarding specimens in the Thaxter collection at the Farlow Herbarium, Harvard University. Throughout the checklist, only naturally occurring fungi associated with field-collected arthropod hosts were included. Samples from laboratory manipulations, often from studies of host specificity, have not been included.

Within the Entomophthoromycotina, extensive taxonomic reorganization has occurred in relatively recent years, and many generic names have changed. For example, in 1963, *Entomophthora* is given as the generic name for all 39 species in the Western Hemisphere (Hutchison 1963). However, for all except 4 of these species, the generic names have since changed. We used Humber (1989), Index Fungorum (<http://www.indexfungorum.org>), and MycoBank (Robert et al. 2005) to assist with all taxonomic decisions about fungi. We only include information from records with fungal identifications to the species level. For all arthropod hosts, only the currently accepted genus and species names are used.

For all records, hosts and distributions are provided with associated citations. For distributional information for North America, we generally referred to states or provinces but also provided citations for references where more specific details about collection site locations were found. For some records, only the name of the country was available. In at least one publication, the locations of species by country were not provided, and this record therefore could not be included (e.g., Remaudière et al. 1978). Two-letter, capitalized abbreviations of US states and Canadian provinces were used. For records from Mexico, we used 'conventional' abbreviations that are 2–4 letters long for states ([https://en.wikipedia.org/wiki/Template:Mexico\\_State-Abbreviation\\_Codes](https://en.wikipedia.org/wiki/Template:Mexico_State-Abbreviation_Codes)). In all cases, the country name occurs alongside states or provinces. GPS coordinates for sites are not included, as for most entries, references are older, and GPS information was not available. Alternatively, descriptions of sites were too vague or broad for us to infer a GPS location. GPS information provided in more recent reports is available via the citations provided.

For information about hosts, only pathogens in the Entomophthoromycotina infecting arthropods were included (Sacco and Hajek 2023). For example, reports of vertebrate infections by *Conidiobolus coronatus* and reports of species only isolated from soil (e.g., many *Conidiobolus* spp.) were not included.

Many arthropod-pathogenic species in the Entomophthoromycotina have not been isolated into pure culture. Among those that have, numerous have been frozen and deposited in culture collections. The USDA-ARS entomopathogenic fungi collection (ARSEF) is the world's largest repository of these isolates, and we have indicated for each species whether a culture is available

in ARSEF. We have not included GenBank accession numbers for numerous reasons, including that DNA data for most of these fungi are lacking or difficult to link to specimens, as many of these are older records prior to the DNA era. We can only confidently link accessions correctly to a few known specimens, and these are scarce. For those fungal species that have been sequenced, accession numbers can be found in the references cited or in GenBank.

References are always provided, but we did not exhaustively include references; if several references report a host/fungus association from the same state/province, we only included one of such references. Summaries were cited if these existed.

## Results

Records for host species and distributions are reported below. For species with more extensive lists of hosts and distributions, detailed accounts are included in tabular form. For example, for some species reported from many states across much of North America, hosts and distribution are summarized below, but individual host species and specific collection locations are listed in tables. Species names below followed by an asterisk have arthropod pathogenic North American isolates in the ARSEF culture collection.

### **Class Neozygitomycetes**

#### **Order Neozygitales**

#### **Family Neozygitaceae**

#### **Neozygites**

##### **[1] *Neozygites floridanus* (J. Weiser & Muma) Remaud. & S. Keller, 1980**

In the US, *N. floridanus* has been reported infecting six species of mites in the family Tetranychidae (Arachnida, Trombidiformes) in the southeastern US states, as well as IA, KS, PA, and TX (US) (Lopes Ribeiro et al. 2009) (Table 1). This species is frequently referred to as *N. floridana*, which is taxonomically incorrect.

**Table 1.** Recorded arthropod hosts of *Neozygites floridanus* in the US, all in the family Tetranychidae (Arachnida, Trombidiformes).

Host Species	Country	States	References
<i>Eotetranychus sexmaculatus</i>	US	FL	Lopes Ribeiro et al. 2009
<i>Eutetranychus banksi</i>	US	FL, TX	Pickett and Gilstrap 1986; Lopes Ribiero et al. 2009
<i>Oligonychus pratensis</i>	US	KS	Dick and Buschman 1995
<i>Panonychus citri</i>	US	FL	Lopes Ribiero et al. 2009
<i>Tetranychus urticae</i>	US	AL, GA, IA, KS, MS, NC, NY, SC	Lopes Ribiero et al. 2009; ARSEF 2020
<i>Bryobia</i> sp.	US	PA	C. Tkaczuk, unpubl. data
-	US	PA	C. Tkaczuk, unpubl. data

##### **[2] *Neozygites fresenii* (Nowak.) Remaud. & S. Keller, 1980**

On multiple aphid species (Hemiptera, Aphididae) from a broad distribution across the US, as well as ON (Canada) and Mexico (Fig. 1, Table 2).



**Figure 1.** Distribution of recorded occurrences of *Neozygites fesenii* in the US, Canada, and Mexico (see references in Table 2). Dark gray = locations by state in the US or province in Canada; light gray = a record from an unspecified area within Mexico.

**Table 2.** Recorded arthropod hosts of *Neozygites fesenii* in the US, Canada, and Mexico, all hosts Hemiptera.

Host Family	Host Species	Country	States/Provinces	References
Aphididae	<i>Aphis glycines</i>	US	AR, NY	Nielsen and Hajek 2005; Galligan 2007
	<i>Aphis gossypii</i>	US	AL, AR, GA, LA, MS, MO, NC, SC, TN, TX	Sanchez-Peña 1993; Steinkraus et al. 1996
	<i>Aphis gossypii</i>	Mex	-	Remaudière and Latgé 1985
	<i>Aphis pomi</i>	US	MA, ME, NC	Thaxter 1888
	<i>Aphis solitaria</i>	Mex	-	Remaudière and Latgé 1985
	<i>Aphis spiraecola</i>	US	FL	Charles 1941
	<i>Capitophorus elaeagni</i>	Mex	-	Remaudière and Latgé 1985
	<i>Myzus persicae</i>	US	FL	Charles 1941
	<i>Periphyllus lyropictus</i>	US	NH	Charles 1941
	<i>Schizaphis graminum</i>	US	ID	Feng et al. 1990
	<i>Schizolachnus piniradiatae</i>	Can	ON	Soper and MacLeod 1963
Pseudococcidae	-	US	PA	C. Tkaczuk, unpubl. data
	<i>Planococcus citri</i>	US	LA	Charles 1941

### [3] *Neozygites fumosus* (Speare) Remaud. & S. Keller, 1980

On the mealybug *Planococcus citri* (Hemiptera, Pseudococcidae) in FL and LA (US) (Speare 1922). This species is frequently referred to as *N. fumosa*, which is taxonomically incorrect.

### [4] *Neozygites lageniformis* (Thaxt.) Remaud. & S. Keller, 1980

Infecting 'Aphides on *Betula populifolia*' and 'Solidago' in MA, ME, and NC (US) (Thaxter 1888), and infecting *Macrosiphum euphorbiae* and *Aphis nasturtii* (Hemiptera, Aphididae) in ME (US) (Shands et al. 1972).

**[5] *Neozygites parvisporus* (D.M. MacLeod & K.P. Carl) Remaud. & S. Keller, 1980**

On *Frankliniella* sp. (Thysanoptera, Thripidae) in BC (Mexico) (Remaudière and Latgé 1985). This species is frequently referred to as *N. parvispora*, which is taxonomically incorrect.

**[6] *Neozygites turbinatus* (R.G. Kenneth) Remaud. & S. Keller, 1980**

On *Cinara curvipes* (Hemiptera, Aphididae, Lachninae) in Jal (Mexico) (Remaudière and Latgé 1985). This species is frequently referred to as *N. turbinata*, which is taxonomically incorrect.

**Class Entomophthoromycetes****Order Entomophthorales****Family Conidiobolaceae*****Conidiobolus*****[7] *Conidiobolus coronatus* (Constantin) A. Batko 1964\***

On diverse insects, including termites (Isoptera, Kalotermitidae and Termitidae), aphids, and leafhoppers (Hemiptera), Diptera, Hymenoptera, and Thysanoptera. A truly polyphagous fungus, this species is also known to infect Collembola (Entognatha), Araneida, and Opiliones (Palpatores). It has been reported from across the US, Ver (Mexico), and AB (Canada) (Hutchison 1963; Matanmi et al. 1974; ARSEF 2020) (Table 3).

**Table 3.** Recorded arthropod hosts of *Conidiobolus coronatus* in the US, Canada, and Mexico.

Host Class	Host Order /Suborder	Host Family	Host Species	Country	States/Provinces	References
Arachnida	Araneida	-	-	Can	AB	ARSEF 2020
	Opiliones/"Palpatores"	-	-	Can	AB	ARSEF 2020
Entognatha	Collembola	-	-	US	NC	ARSEF 2020
Insecta	Diptera	Anthomyiidae	<i>Delia platura</i>	US	WI	Matanmi et al. 1974
			<i>Delia radicum</i>	US	WI	Matanmi et al. 1974
		Bibionidae	<i>Plecia nearctica</i>	US	FL	Kish et al. 1974
		Sciaridae	<i>Lycoriella ingenua</i>	Mex	Ver	ARSEF 2020
	Hemiptera	Aphididae	<i>Aulacorthum solani</i>	US	ME	Harris 1948
			<i>Macrosiphum euphorbiae</i>	US	ME	Harris 1948
			<i>Metopolophium dirhodum</i>	US	ID	ARSEF 2020
			<i>Myzus persicae</i>	US	ME	Harris 1948
	Cercopidae	<i>Aeneolamia albofasciata</i>	Mex	Oax	Remaudière and Latgé 1985	
		<i>Aeneolamia contigua</i>	Mex	Tamps	Guzmán and Alcocer-Gómez 1972	
	Cicadellidae	<i>Empoasca fabae</i>	US	NY	ARSEF 2020	
Hymenoptera	Formicidae	-	Can	AB	ARSEF 2020	
Isoptera	Kalotermitidae	-	US	CA, LA	Hutchison 1963	
	Termitidae	-	US	CA, LA	Hutchison 1963	
Orthoptera	Acrididae	-	Mex	-	Remaudière and Latgé 1985	
Thysanoptera	Thripidae	-	US	VT	ARSEF 2020	
		<i>Frankliniella occidentalis</i>	US	FL	ARSEF 2020	

**Family Neoconidiobolaceae**  
***Neoconidiobolus***

**[8] *Neoconidiobolus thrombooides* (Drechsler) B. Huang & Y. Nie, 2020\***

Well known as an aphid (Hemiptera, Aphididae) pathogen: on numerous aphid hosts across the US and in AB, ON, and QC (Canada). It has also been reported from another hemipteran, the leafhopper *Empoasca fabae* in NY (US) (Hemiptera, Cicadellidae), a heleomyzid fly in ME (US) (Diptera, Heliomyzidae), and an acridid in MT (US) (Orthoptera, Acrididae) (ARSEF 2020; Castrillo and Harris-Shultz 2024). *Delia radicum* and *Delia platura* (Diptera, Anthomyiidae) were also reported infected in WI (US) (Matanmi et al. 1974) (Table 4).

**Table 4.** Recorded arthropod hosts of *Neoconidiobolus thrombooides* in the US and Canada.

Host Order	Host Family	Host Species	Country	States/ Provinces	References
Diptera	Anthomyiidae	<i>Delia platura</i>	US	WI	Matanmi et al. 1974
		<i>Delia radicum</i>	US	WI	Matanmi et al. 1974
	Heliomyzidae	-	US	ME	ARSEF 2020
Hemiptera	Aphididae	<i>Aphis glycines</i>	US	MN, NY	Nielsen and Hajek 2005
		<i>Diuraphis tritici</i>	US	MT	Feng et al. 1991
		<i>Macrosiphum euphorbiae</i>	US	ME	ARSEF 2020
		<i>Melanaphis sacchari</i>	US	GA	Castrillo and Shultz 2024
		<i>Metopolophium dirhodum</i>	US	ID	ARSEF 2020
		<i>Myzus persicae</i>	US	FL, ME, WI	ARSEF 2020
		<i>Schizaphis graminum</i>	Can	AB	ARSEF 2020
		<i>Sitobion avenae</i>	US	ID	ARSEF 2020
		<i>Theroaphis maculata</i>	US	CA	ARSEF 2020
	Cicadellidae	<i>Uroleucon</i> sp.	Can	QC	ARSEF 2020
Orthoptera	Acrididae	<i>Empoasca fabae</i>	US	NY	ARSEF 2020

**Family Batkoaceae**  
***Batko***

**[9] *Batko apiculata* (Thaxt.) Humber, 1989\***

Broad host range including four families of Lepidoptera (Erebidae, Noctuidae, Tortricidae, Geometridae), numerous aphid species (Hemiptera, Aphididae), leafhoppers (Hemiptera, Cicadellidae), a spittlebug (Hemiptera, Cercopidae), Scirtidae and Helotidae (Coleoptera), and nematocerans (Diptera). Collected across the northern US, as far south in the US as TN and NC but also in SLP (Mexico) (Thaxter 1888; Hutchison 1963; ARSEF 2020) (Table 5).

**[10] *Batko major* (Thaxt.) Humber, 1989\***

Initially, described from Ptilodactylidae (Coleoptera) in NC (US) by Thaxter (1888). Epizootics occurred in *Lycorma delicatula*, an invasive species in the Fulgoridae (Hemiptera) in PA (US) in 2018 (Clifton et al. 2019). Following field surveys of host range in PA and NY (US), confirmed infections were observed in 3 families of Coleoptera, 8 families of Diptera, 5 families of Hemiptera, 6 families of Lepidoptera, and 1 family of Psocomorpha (Gryganskyi et al. 2022a) (Table 6).

**Table 5.** Recorded arthropod hosts of *Batko a apiculata* in the US and Mexico.

Host Order	Host Family/Suborder	Host Species/Subfamily	Country	States	References
Coleoptera	Cantharidae	-	Mex	Oax	Remaudière and Latgé 1985
	Scirtidae	-	US	TN	Hutchison 1963
Diptera	Nematocera	-	US	ME, NC	Thaxter 1888
		-	Mex	Tamps	Remaudière and Latgé 1985
Hemiptera	Aphididae	<i>Acyrtosiphon pisum</i>	US	NY	ARSEF 2020
	Aphididae	<i>Macrosiphum euphorbiae</i>	US	ME	ARSEF 2020
	Aphididae	<i>Myzus persicae</i>	US	ME	ARSEF 2020
	Aphididae	<i>Rhopalosiphum maidis</i>	US	MT	ARSEF 2020
	Aphididae	<i>Rhopalosiphum padi</i>	US	CO	ARSEF 2020
	Cercopidae	<i>Prosapia simulans</i>	Mex	-	Remaudière and Latgé 1985
	Cicadellidae	-	US	NH, NY	ARSEF 2020
	Cicadellidae	<i>Typhlocyba</i> sp.	US	ME, NC	Thaxter 1888
Lepidoptera	Erebidae	<i>Hyphantria cunea</i>	US	ME, NC	Thaxter 1888
	Erebidae	listed as 'Deltoid sp.'	US	ME, NC	Thaxter 1888
	Geometridae	<i>Petrophora</i> sp.	US	ME, NC	Thaxter 1888
	Tortricidae	<i>Tortrix</i> sp.	US	ME, NC	Thaxter 1888

**Table 6.** Recorded arthropod hosts of *Batko a major* in the US and Mexico.

Host Order	Host Family	Host Species	Country	States	References
Coleoptera	Cantharidae	<i>Rhagonycha fraxini</i>	US	NY	Gryganskyi et al. 2022a
		<i>Rhagonycha</i> sp.	US	NY	Gryganskyi et al. 2022a
	Elateridae	<i>Athous brightwelli</i>	US	NY	Gryganskyi et al. 2022a
	Ptilodactylidae	<i>Ptilodactyla serricollis</i>	US	NC	Thaxter 1888
	Tenebrionidae	<i>Isomira sericea</i>	US	NY	Gryganskyi et al. 2022a
Diptera	Anthomyiidae	-	US	NY	Gryganskyi et al. 2022a
	Dolichopodidae	<i>Gymnopterus</i> sp.	US	NY	Gryganskyi et al. 2022a
		<i>Medetera</i> sp.	US	PA	Gryganskyi et al. 2022a
		<i>Thrypticus</i> sp.	US	NY	Gryganskyi et al. 2022a
	Drosophilidae	<i>Drosophila suzukii</i>	US	TN	ARSEF 2020
	Heleomyzidae	<i>Tephrochlamys rufiventris</i>	US	NY	Gryganskyi et al. 2022a
	Lauxaniidae	<i>Homoneura inserta</i>	US	NY, PA	Gryganskyi et al. 2022a
	Milichiidae	<i>Madiza glabra</i>	US	PA	Gryganskyi et al. 2022a
	Psychodidae	-	US	NY	Gryganskyi et al. 2022a
	Rhagionidae	-	US	NY	Gryganskyi et al. 2022a
		<i>Syphoromyia</i> sp.	US	NY	Gryganskyi et al. 2022a
	Sciaridae	-	US	NY, PA	Gryganskyi et al. 2022a
Hemiptera	Achilidae	-	US	NY	Gryganskyi et al. 2022a
	Aphididae	<i>Macrosiphum euphorbiae</i>	US	ME	ARSEF 2020
	Cercopidae	<i>Prosapia simulans</i>	Mex	Chis, Tamps	Remaudière and Latgé 1985
	Cicadellidae	-	US	NY	Gryganskyi et al. 2022a
		<i>Empoasca fabae</i>	US	NY	ARSEF 2020
	Cixiidae	<i>Cixius</i> sp.	US	NY	Gryganskyi et al. 2022a
	Derbidae	<i>Apache degeeri</i>	US	NY	Gryganskyi et al. 2022a
Lepidoptera	Fulgoridae	<i>Lycorma delicatula</i>	US	PA	Gryganskyi et al. 2022a
	Blastobasidae	-	US	NY	Gryganskyi et al. 2022a
	Crambidae	<i>Eudonia</i> sp.	US	NY	Gryganskyi et al. 2022a
	Erebidae	<i>Lophocampa caryae</i>	US	NY	Gryganskyi et al. 2022a
		<i>Lymantria dispar</i>	US	NY	Gryganskyi et al. 2022a
	Geometridae	<i>Lambdina fiscellaria</i>	US	NY	Gryganskyi et al. 2022a
Psocoptera	Oecophoridae	<i>Fabiola edithella</i>	US	NY	Gryganskyi et al. 2022a
	Tineidae	<i>Dryadaula</i> sp.	US	NY	Gryganskyi et al. 2022a
Psocoptera	Amphipsocidae	<i>Polypsocus corruptus</i>	US	NY	Gryganskyi et al. 2022a
	Psocomorpha	-	US	PA	Gryganskyi et al. 2022a

**[11] *Batkoia obscura* (I.M. Hall & P.H. Dunn) Gryganskyi, 2022\***

On numerous species of aphids in CA, NY, ID, MT, and ME (US) and QC (Canada) (Table 7).

**Table 7.** Recorded arthropod hosts of *Batkoia obscura* in the US, Canada, and Mexico, all in the family Aphididae (Hemiptera).

Host Species	Country	States/ Provinces	References
<i>Acyrtosiphon pisum</i>	US	NY	ARSEF 2020
<i>Aphis nasturtii</i>	US	ME	Shands et al. 1972
<i>Aphis</i> sp.	Can	QC	ARSEF 2020
<i>Aulacorthum solani</i>	US	ME	Shands et al. 1972
<i>Capitophorus elaeagni</i>	Mex	-	Remaudiére and Latgé 1985
<i>Capitophorus shepherdiae</i>	Mex	-	Remaudiére and Latgé 1985
<i>Capitophorus xanthii</i>	Mex	-	Remaudiére and Latgé 1985
<i>Hyperomyzus lactucae</i>	Mex	-	Remaudiére and Latgé 1985
<i>Macrosiphum euphorbiae</i>	US	ME	Shands et al. 1962
<i>Macrosiphum</i> spp.	Mex	-	Remaudiére and Latgé 1985
<i>Metopolophium dirhodum</i>	US	MT	Feng et al. 1991
<i>Microparsus (Picturaphis)</i> sp.	Mex	-	Remaudiére and Latgé 1985
<i>Myzus persicae</i>	US	ME	Shands et al. 1962
<i>Myzus persicae</i>	Mex	-	Remaudiére and Latgé 1985
<i>Rhopalosiphum maidis</i>	US	MT	Feng et al. 1991
<i>Rhopalosiphum maidis</i>	Mex	-	Remaudiére and Latgé 1985
<i>Rhopalosiphum padi</i>	Can	QC	ARSEF 2020
<i>Rhopalosiphum padi</i>	Mex	-	Remaudiére and Latgé 1985
<i>Rhopalosiphum</i> sp.	Mex	-	Remaudiére and Latgé 1985
<i>Theroaphis maculata</i>	US	CA	ARSEF 2020
<i>Uroleucon ambrosiae</i>	Mex	-	Remaudiére and Latgé 1985
<i>Uroleucon sonchi</i>	Mex	-	Remaudiére and Latgé 1985
<i>Uroleucon</i> sp.	Can	QC	ARSEF 2020
<i>Uroleucon</i> sp.	Mex	-	Remaudiére and Latgé 1985

**[12] *Batkoia papillata* (Thaxt.) Humber, 1989**

On 'several minute gnats' (Diptera, Nematocera) from NH and NC (US). In North America, known only from these initial collections by Thaxter (1888).

**Family Entomophthoraceae**  
**Subfamily Entomophthoroideae**  
**Arthrophaga**

**[13] *Arthrophaga myriapodina* K.T. Hodge & A.E. Hajek, 2017**

Reported from three species of millipedes (Myriapoda, Polydesmidae): *Apheloria virginiana corrugata*, *Nannaria* sp., and *Boraria infesta* in MA, MD, NC, NY, PA, and VA, Washington DC (US), and southern ON (Canada) (Hodge et al. 2017).

***Entomophaga*****[14] *Entomophaga aulicae* (E. Reichardt) Humber, 1984 (*aulicae* species complex)\***

*Entomophaga aulicae* is a complex of morphologically identical species infecting only Lepidoptera, within which only *E. maimaiga* has been named as a separate species (treated below). Aside from *E. maimaiga*, fungal populations belonging to the *E. aulicae* complex infect lepidopteran species in the Noctuidae, Erebidae, Geometridae, Tortricidae, Lasiocampidae, Notodontidae, Sphingidae, and Saturniidae families from around the US and Canada (FPMI 1990; Walsh 1996; Speare and Colley 1912; ARSEF 2020). An invasive species in the Hesperiidae (Lepidoptera) in QC (Canada) was also infected (McNeil and MacLeod 1982). Within the complex, genetic diversity has been detected, with two groups occurring in North America. Pathotype I includes hosts in the Geometridae, Tortricidae, Notodontidae, and Saturniidae from BC, ON, and NF (Canada) and ME, NY, and VT (US). Pathotype II includes species in the Noctuidae and Erebidae in GA, CA (US), and ON (Canada) (Hajek et al. 1996b; Walsh et al. 1990; Walsh 1996) (Table 8).

**Table 8.** Recorded arthropod hosts of *Entomophaga aulicae* in the US, Canada, and Mexico, with all hosts in the order Lepidoptera.

Host Family	Host species	Country	States/ Provinces	References	Group
Erebidae	<i>Catocala</i> sp.	US	CT	Speare and Colley 1912	-
	<i>Estigmene acrea</i>	US	CT	Speare and Colley 1912	-
	<i>Estigmene acrea</i>	Mex	Son	Young and Sifuentes 1959	-
	<i>Euchaetes egle</i>	US	-	Speare and Colley 1912	-
	<i>Euproctis chrysorrhoea</i>	US	MA, ME	Kirkland 1906; Boyd et al. 2021	-
	<i>Hypena scabra</i>	US	SC	Kalkar and Carner 2005	-
	<i>Hyphantria cunea</i>	Can	ON	Walsh et al. 1990	II
	<i>Orgyia antiqua nova</i>	Can	NF	Thaxter 1888	-
	<i>Orgyia leucostigma</i>	Can	NS	van Frankenhuyzen et al. 2002	-
	<i>Orgyia vetusta</i>	US	CA	Hajek et al. 1996b	II
Geometridae	<i>Pyrrharctia isabella</i>	US	ME	Hitchings 1908	-
	<i>Spilosoma virginica</i>	US	OH, TX	Webster 1894; Mitchell 1919	-
	<i>Epirrita autumnata</i>	Can	BC	FPMI 1990	-
	<i>Lambdina fiscellaria</i>	Can	BC, NF	Walsh et al. 1990; Hajek et al. 1996b	I
	<i>Nepytia freemani</i>	Can	BC	FPMI 1990	-
	<i>Rheumaptera hastata</i>	Can	ON	Walsh et al. 1990	I
	<i>Sabulodes griseata</i>	Can	BC	ARSEF 2020	-
	<i>Malacosoma americanum</i>	US	CT	Speare and Colley 1912	-
	<i>Malacosoma disstria</i>	US	NY	ARSEF 2020	-
	<i>Agrotis</i> sp.	US	CT	Thaxter 1891	-
Noctuidae	<i>Amphipyra pyramidoides</i>	US	-	Speare and Colley 1912	-
	<i>Helicoverpa zea</i>	US	GA	Hamm 1980	-
	? <i>Heliothis</i> sp.	US	GA	Walsh et al. 1990	II
	<i>Heliothis virescens</i>	US	GA	Hamm 1980	-
	<i>Lithophane</i> sp.	US	CT	Thaxter 1891	-
	<i>Mamestra</i> sp.	US	CT	Thaxter 1891	-
	<i>Mythimna</i> sp.	Can	ON	ARSEF 2020	-
	<i>Spodoptera frugiperda</i>	US	GA	Hamm 1980	-
	<i>Nola cereella</i>	US	GA	Hamm 1980	-
Nolidae					

Host Family	Host species	Country	States/ Provinces	References	Group
Notodontidae	<i>Cecrita biundata</i>	Can	ON	ARSEF 2020	
	<i>Cecrita guttivitta</i>	US	NY, VT	Hajek et al. 1991; 1996b	I
	<i>Ellida caniplaga</i>	Can	ON	ARSEF 2020	-
Saturniidae	<i>Dryocampa rubicunda</i>	Can	ON	Walsh et al. 1990	I
Sphingidae	-	US	ME	FPMI 1990	-
	<i>Manduca quinquemaculata</i>	US	CT	Thaxter 1891	-
	<i>Manduca sexta</i>	US	CT	Thaxter 1891	-
	<i>Pachysphinx modesta</i>	US	ME	Farlow Herbarium unpubl. data	-
	<i>Eumorpha fasciata</i>	US	FL	ARSEF 2020	-
Tortricidae	<i>Choristoneura fumiferana</i>	US	ME	Walsh et al. 1990	
	<i>Choristoneura fumiferana</i>	Can	NF, ON	Walsh et al. 1990	I
	<i>Choristoneura occidentalis</i>	Can	BC	Hajek et al. 1996b	I

**[15] *Entomophaga batkoi* (Bałazy) S. Keller, 1888**

On a species in the Phalangidae in ME (US) (R.A. Humber pers. comm.).

**[16] *Entomophaga calopteni* (Bessey) Humber, 1989 (*E. grylli* species complex)\***

A member of the *Entomophaga grylli* species complex, also known as Pathotype 2. Infects species in the Acrididae, with most infections in the subfamily Melanoplinae, although lower levels of infection have been found in the subfamilies Oedopodinae and Gomphocerinae. Reported from AZ, IA, KS, MT, ND, SD, and WY (US), AB and SK (Canada), and NL and Coah (Mexico) (Thaxter 1888; Soper et al. 1983; Erlandson et al. 1988; Bidochka et al. 1995, 1996; Casique-Valdes et al. 2012, 2022; ARSEF 2020).

**[17] *Entomophaga grylli* Pathotype I (Fresen.) A. Batko, 1964 (*E. grylli* species complex)\***

A member of the *Entomophaga grylli* species complex, also known as Pathotype 1 or *E. macleodii* (an unpublished name). Principally infects grasshopper species in the subfamily Oedopodinae (Acrididae), although also known to infect Gomphocerinae and occasionally Melanoplinae. Reported from AZ, ND, NY, MT, and OR (US), and AB, ON, and SK (Canada), and Coah (Mexico) (Bidochka et al. 1996; Casique-Valdes et al. 2012, 2022; Kistner and Belovsky 2013; ARSEF 2020).

**[18] *Entomophaga kansana* (J.A. Hutchison) A. Batko, 1964**

Reported from Calliphoridae, Sarcophagidae, Muscidae, and Tachinidae (Diptera) near Lawrence, KS (US) (Hutchison 1962).

**[19] *Entomophaga maimaiga* Humber, Shimazu & R.S. Soper, 1988 (*aulicae* species complex)\***

*Entomophaga maimaiga* is a North Asian species only infecting Lepidoptera, accidentally introduced to North America, probably from Japan, at some time after 1971, but before 1989 (Weseloh 1998; Nielsen et al. 2005). Principal hosts are larvae of *Lymantria dispar* (Lepidoptera, Erebidae). Surveys of naturally occurring host specificity documented low levels of infections in 3 of 7 lymantriines (Hajek

et al. 2004). Rare infections also occurred in *Catocala ilia* (Erebidae) and *Malacosoma disstria* (Lasiocampidae) (Hajek et al. 1996a), *Agrochola bicolorago* (Noctuidae); an unidentified gelechiid (Lepidoptera) was also infected (Hajek et al. 2000). *E. maimaiga* was discovered in 1989 in seven northeastern US states (Hajek et al. 1990) and has since spread (naturally and with human assistance)



**Figure 2.** Distribution of recorded occurrences of *Entomophaga maimaiga* in the US and Canada, by state and province (Hajek et al. 2021; S. Picq pers. comm.).

into a total of 19 US states (Hajek et al. 2021). *E. maimaiga* has also been reported from ON and QC (Canada) (Nealis et al. 1999, S. Picq pers. comm.) (Fig. 2).

**[20] *Entomophaga tabanivora* (J.F. Anderson & Magnar.) Humber, 1989**

On *Tabanus nigrovittatus* and *Atylotus thoracicus* (Diptera, Tabanidae) in MA and NY (US) (Anderson and Magnarelli 1979; Mullens et al. 1983).

**[21] *Entomophaga tenthredinis* (Fresen.) A. Batko, 1964**

On sawfly larvae (Hymenoptera, Tenthredinidae), including *Pristiphora erichsonii* in ON (Canada), larvae of an unidentified tenthredinid species in ME (US), and the introduced pine sawfly, *Diprion similis*, in WI (US) (Thaxter 1888; Klein and Coppel 1973; FPMI 1990).

***Entomophthora***

**[22] *Entomophthora chromaphidis* O.F. Burger & Swain, 1918**

An aphid pathogen (Hemiptera, Aphididae) on *Chromaphis juglandicola* in CA (Burger and Swain 1918), the cereal aphids *Metopolophium dirhodum* in ID, WA (US) and *Sitobion avenae* in ID (US) (Humber and Feng 1991), *Myzus per-*

sicae in ID (Kish et al. 1994), and *Aphis glycines* in NY (US) (Nielsen and Hajek 2005). Also reported on *Psocus* sp. (Psocodea, Psocidae) in CA (US) (Burger and Swain 1918). At least some of the entries under *E. planchoniana* (Table 9) could instead be *E. chromaphidis* (see Humber and Feng 1991; Barta and Cagán 2006); further study is necessary.

### [23] *Entomophthora culicis* (A. Braun) Fresen., 1858

Reported by Thaxter (1888) on Diptera: "Culex [Culicidae], and numerous genera of minute flies or gnats" in MA, ME, and NH. On unidentified midges (Chironomidae) in NY (US) (Kramer 1981b) and unidentified black flies (Simuliidae) in AB (Canada) (Shemanchuk and Humber 1978).

### [24] *Entomophthora erupta* (Dustan) I.M. Hall, 1959

On Miridae (Hemiptera): *Neolygus communis*, *Adelphocoris lineolatus*, *Irbisia solani*, *Lygocoris pabulinus*, and *Plagiognathus* sp. in NS (Canada) (Dustan 1924), and *I. solani* in CA (US) (Hall 1959). Also reported from *A. lineolatus* from NY (US) (Wheeler 1972).

### [25] *Entomophthora muscae* (Cohn) Fresen., 1856\*

*Entomophthora muscae* is a species complex of morphologically similar species infecting Diptera, including from 4 to 8 described species (Elya and De Fine Licht 2021). Three species within the complex occur in North America: *E. muscae sensu stricto* (s.s), *E. scatophagae* (treated separately), and *E. schizophorae* (treated separately). *Entomophthora muscae* s.s infects *Musca domestica* (Muscidae) in CA, NY, NC, and NE, and probably across most of the US and Canada, and in Coah (Mexico) (Sanchez-Peña unpubl. observations). Also on *Coenosia tigrina* (Muscidae) and *Delia radicum* (Anthomyiidae) in NC (US) (Gryganskyi et al. 2013), and six species of *Drosophila* (Drosophilidae) in CA (US): *Drosophila melanogaster*, *D. simulans*, *D. hydei*, *D. immigrans*, *D. pseudoobscura*, *D. repleta* (Elya et al. 2018). Further studies of hosts and distributions of the different members of this species complex in North America are necessary.

### [26] *Entomophthora planchoniana* Cornu, 1873

On diverse species of aphids (Aphididae) across the US and Mexico (Table 9). However, at least some of the entries under *E. planchoniana* in Table 9 could instead be *E. chromaphidis* (see Humber and Feng 1991; Barta and Cagán 2006); further study is necessary.

**Table 9.** Recorded arthropod hosts of *Entomophthora planchoniana* in the US and Mexico, with all hosts in the family Aphididae (Hemiptera).

Host Species	Country	States	References
<i>Acyrtosiphon malvae</i>	Mex	-	Remaudière and Latgé 1985
<i>Acyrtosiphon pisum</i>	Mex	-	Remaudière and Latgé 1985
<i>Aphis asclepiadis</i>	Mex	-	Remaudière and Latgé 1985
<i>Aphis coreopsis</i>	Mex	-	Remaudière and Latgé 1985

Host Species	Country	States	References
<i>Aphis fabae</i>	Mex	-	Remaudière and Latgé 1985
<i>Aphis gossypii</i>	Mex	-	Remaudière and Latgé 1985
<i>Aphis lugentis</i>	Mex	-	Remaudière and Latgé 1985
<i>Aphis nasturtii</i>	US	ME	Shands et al. 1972
<i>Aphis solitaria</i>	Mex	-	Remaudière and Latgé 1985
<i>Aphis spiraecola</i>	Mex	-	Remaudière and Latgé 1985
<i>Aulacorthum solani</i>	US	ME	Shands et al. 1972
<i>Brevicoryne brassicae</i>	Mex	-	Remaudière and Latgé 1985
<i>Capitophorus elaeagni</i>	Mex	-	Remaudière and Latgé 1985
<i>Capitophorus shepherdiae</i>	Mex	-	Remaudière and Latgé 1985
<i>Capitophorus xanthii</i>	Mex	-	Remaudière and Latgé 1985
<i>Chaetosiphon fragaefolii</i>	US	CA	Dara 2017
<i>Cryptomyzus galeopsidis</i>	US	ME	Shands et al. 1962
<i>Hayhurstia atriplicis</i>	Mex	-	Remaudière and Latgé 1985
<i>Hyperomyzus</i> sp.	Mex	-	Remaudière and Latgé 1985
<i>Latgerina orizabaensis</i>	Mex	-	Remaudière and Latgé 1985
<i>Macrosiphum euphorbiae</i>	US	ME	Shands et al. 1962
<i>Macrosiphum</i> spp.	Mex	-	Remaudière and Latgé 1985
<i>Melanocallis caryaefoliae</i>	US	GA	Ekbom and Pickering 1990
<i>Metopolophium dirhodium</i>	US	ID	Feng et al. 1991
<i>Metopolophium dirhodium</i>	Mex	BC	Remaudière and Latgé 1985
<i>Monellia caryella</i>	US	GA	Ekbom and Pickering 1990
<i>Monelliopsis pecanis</i>	US	GA	Ekbom and Pickering 1990
<i>Myzus ornatus</i>	Mex	-	Remaudière and Latgé 1985
<i>Myzus persicae</i>	US	ME	Shands et al. 1962
<i>Myzus persicae</i>	Mex	-	Remaudière and Latgé 1985
<i>Obtusicauda</i> sp.	Mex	BC	Remaudière and Latgé 1985
<i>Rhopalosiphum maidis</i>	US	ID	Feng et al. 1991
<i>Rhopalosiphum maidis</i>	Mex	Coah	Sanchez-Peña 2000
<i>Rhopalosiphum padi</i>	Mex	BC	Remaudière and Latgé 1985
<i>Rhopalosiphum padi</i>	Mex	-	Remaudière and Latgé 1985
<i>Rhopalosiphum</i> sp.	Mex	-	Remaudière and Latgé 1985
<i>Sitobion avenae</i>	US	ME	Shands et al. 1962
<i>Uroleucon ambrosiae</i>	Mex	-	Remaudière and Latgé 1985
<i>Uroleucon sonchi</i>	Mex	-	Remaudière and Latgé 1985
<i>Uroleucon</i> sp.	Mex	-	Remaudière and Latgé 1985
<i>Utamphorophora crataegi</i>	Mex	-	Remaudière and Latgé 1985

### [27] *Entomophthora scatophagae* Giard, 1888

A member of the *E. muscae* species complex (Jensen et al. 2006). On *Scatophaga stercoraria* (Diptera, Anthomyiidae) in NY (Steinkraus and Kramer 1988).

### [28] *Entomophthora schizophorae* S. Keller & Wilding, 1988

A member of the *E. muscae* species complex, infecting only Diptera (Elya and De Fine Licht 2021). Isolates from NE and NY (US) infect *Pollenia rudis* (Diptera, Polleniidae), and both also infect *Musca domestica*, although at lower prevalence (Steinkraus et al. 1993a; Watson et al. 1993; Six and Mullens 1996). Also, infects *Hylemya* sp. (Anthomyiidae) in PA (US) (C. Tkaczuk unpubl. data).

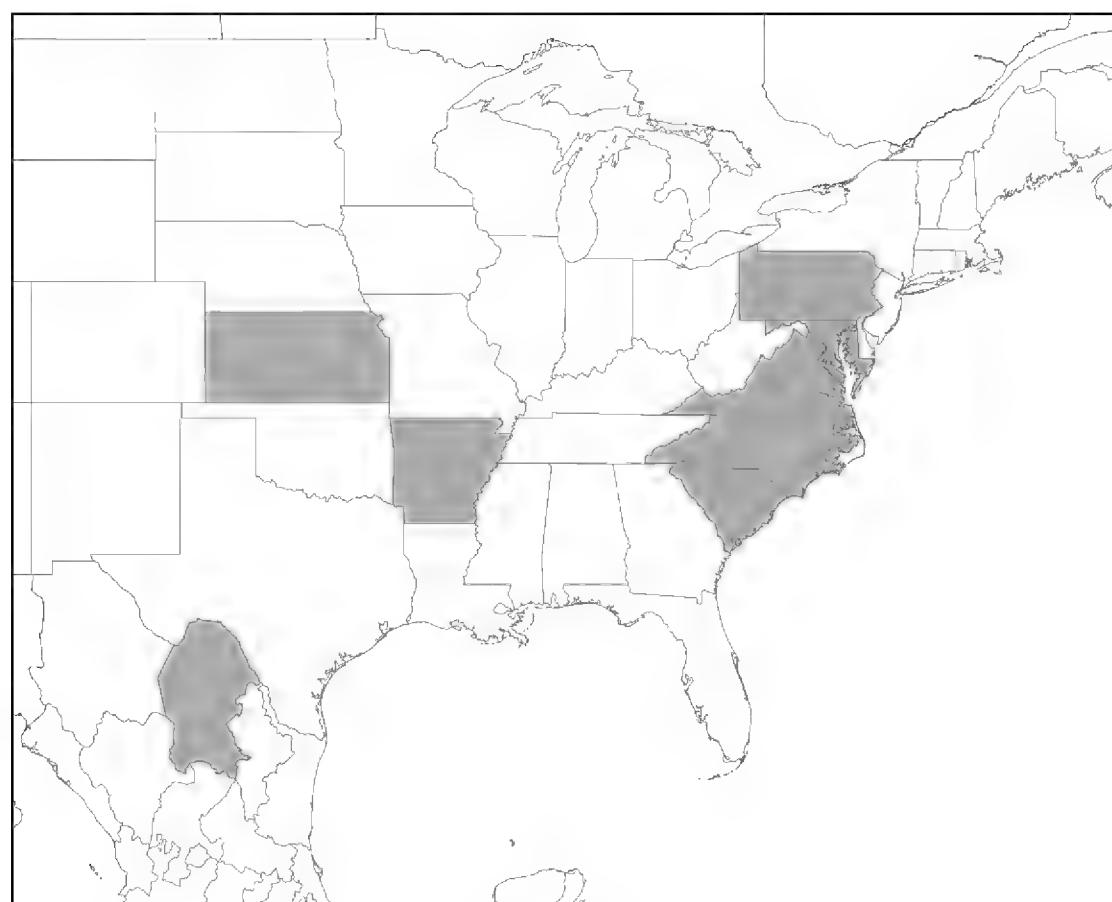
### *Eryniopsis*

#### [29] *Eryniopsis caroliniana* (Thaxter) Humber, 1984

On *Tipula* sp. (Diptera, Tipulidae) in NC (US) (Thaxter 1888).

**[30] *Eryniopsis lampyridarum* (Thaxter) Humber, 1984**

On *Chauliognathus pensylvanicus* and *Chauliognathus marginatus* (Coleoptera, Cantharidae) in AR, MD, KS, NC, PA, SC, and VA (US) (Thaxter 1888; Carner 1980; Steinkraus et al. 2017) (Fig. 3). Also, on *Chauliognathus* sp. in Coah (Mexico) (RI Torres-Acosta & S. Sanchez-Peña, unpubl. observation: <https://www.youtube.com/watch?v=NRBO7zc1J-o>).



**Figure 3.** Distribution of recorded occurrences of *Eryniopsis lampyridarum* in the US and Mexico, by state (see references in the text).

**Massospora**

**[31] *Massospora cicadina* Peck, 1878\***

On species of the genus *Magicicada* (Hemiptera, Cicadidae) in the eastern US (Macias et al. 2020).

**[32] *Massospora diceroproctae* R.S. Soper, 1974**

On *Diceroprocta delicata*, *Diceroprocta cinctifera*, *Diceroprocta vitripennis*, and *Diceroprocta biconica* (Hemiptera, Cicadidae) in TX (and possibly LA, FL) (US) (Macias et al. 2020).

**[33] *Massospora fidicinae* R.S. Soper, 1974**

On *Fidicina* sp. (Hemiptera, Cicadidae) in Chis (Mexico) (Macias et al. 2020).

**[34] *Massospora levispora* R.S. Soper, 1963**

On *Okanagana rimosa* and *Okanagana sperata* (Hemiptera, Cicadidae) in CA (US) and ON (Canada) and *Platypedia putnami* (Hemiptera, Cicadidae) in CA, NM, and UT (US) (Macias et al. 2020).

**[35] *Massospora spinosa* Cif., A.A. Machado & Vittal, 1956**

On *Quesada gigas* (Hemiptera, Cicadidae) in NL (Mexico) (Macias et al. 2020).

***Orthomyces***

**[36] *Orthomyces aleyrodis* Steinkr., Humber & Oliv., 1998**

On *Trialeurodes abutiloneus* (Hemiptera, Aleyrodidae) in AL (US) (Steinkraus et al. 1998).

**Subfamily Erynioideae**

***Erynia***

**[37] *Erynia aquatica* (J.F. Anderson & Ringo ex J.F. Anderson & Anagnost.) Humber, 1981\***

On larvae and pupae of Culicidae (Diptera) in the US: *Aedes canadensis* (CT, RI), *Culiseta morsitans* (CT), *Aedes stimulans* (NY), *Aedes fitchii* (NY), *Aedes cantator* (CT), *Aedes* sp. (NY) (Anderson and Ringo 1969; Molloy and Wraight 1982; Andreadis and Magnarelli 1983; Steinkraus and Kramer 1989; Christie 1996; ARSEF 2020).

**[38] *Erynia conica* (Nowak.) Remaud. & Hennebert, 1980\***

On Chironomidae, Chaoboridae, Simuliidae, and Tipulidae (Diptera) in NC, NH, and NY (US) (Thaxter 1888; Cuevas-Incle 1992; ARSEF 2020). On Simuliidae (Diptera) in QC (Canada): *Simulium venustum* complex, *Simulium verecundum/rostratum*, *Simulium vittatum* complex (Nadeau et al. 1994).

**[39] *Erynia curvispora* (Nowak.) Remaud. & Hennebert, 1980\***

Reported from adult *Simulium decorum* (Diptera, Simuliidae) in NY (US) and QC (Canada) (Kramer 1983; Nadeau et al. 1994), *Aedes triseriatus* (Diptera, Culicidae) in ME (US), and unidentified *Simulium* in NY (US) and QC (Canada) and Trichoptera in QC (Canada) (ARSEF 2020).

**[40] *Erynia gracilis* (Thaxter) Remaud. & Hennebert, 1980**

On “very minute gnats” (Diptera) in NC (US) (Thaxter 1888).

**[41] *Erynia ovispora* (Nowak.) Remaud. & Hennebert, 1980**

On a ‘small gnat attached to bark’ in TN (Diptera) (US) (R.A. Humber pers. comm.).

**[42] *Erynia rhizospora* (Thaxter) Remaud. & Hennebert, 1980\***

On Neuroptera and “several genera” of adult Phryganeidae (Trichoptera) in ME and NC (US) (Thaxter 1888). Also reported on Trichoptera in NY (US) (ARSEF 2020).

**[43] *Erynia sepulchralis* (Thaxter) Remaud. & Hennebert, 1980\***

On unidentified adult crane flies (Diptera, Tipulidae) in western NC and eastern TN (US) (Thaxter 1888), and on *Tipula caloptera* in NY (US) (Kramer 1980).

**[44] *Erynia variabilis* (Thaxter) Remaud. & Hennebert, 1980**

On ‘minute gnats of various genera’ in NC (Diptera) (US) (Thaxter 1888).

***Pandora***

**[45] *Pandora americana* (Thaxter) S. Keller, 2007**

On Diptera: *Musca domestica* (Muscidae), *Calliphora vomitoria*, and *Lucilia caesar* (Calliphoridae) and ‘numerous other large flies.’ Common in New England and less common in NC (US) (Thaxter 1888). Also reported in the US from *Calliphora* sp. (WI), *C. vomitoria* (AL), *Phormia regina* (TX) (Calliphoridae), and *Muscina stabulans* (TN) (Muscidae) (Charles 1941).

**[46] *Pandora blissi* (G. Lakon) D.M. MacLeod & Müller-Kögler, 1973; *nomen dubium***

On the chinch bug, *Blissus leucopterus* (Hemiptera, Blissidae) in IA, IL, KS, MN, and OH (Billings and Glenn 1911). This species was initially placed in the genus *Empusa* by Thaxter (Gillette 1888). The 1888 species description was minimal (Gillette 1888), and no types were designated (but ‘co-types’ are present at Harvard). The provisional genus *Pandora* is based on ongoing evaluation of museum specimens.

**[47] *Pandora blunckii* (G. Lakon ex G. Zimm.) Humber, 1989\***

On *Plutella xylostella* (Lepidoptera, Plutellidae) in Gto. (Mexico) (ARSEF 2020) and on Diptera (possibly Sciaridae) in NY (US) (ARSEF 2020).

**[48] *Pandora bullata* (Thaxt. & D.M. MacLeod ex Humber) Humber, 1989**

On Calliphoridae (Diptera): including *Phormia regina*, *Lucilia sericata*, *Protophormia terraenovae*, *Calliphora vomitoria*, and perhaps other *Calliphora* spp. and Sarcophagidae (Diptera): *Sarcophaga aldrichi* in ON (Canada) and NY, MI, and MA (US) (MacLeod et al. 1973; Kramer 1979; Nielsen et al. 2001).

**[49] *Pandora delphacis* (Hori) Humber, 1989\***

On Hemiptera: *Spissistilus festinus* (Hemiptera, Membracidae) in AL, AR (US) (Miller and Harper 1987; ARSEF 2020), and *Empoasca fabae* (Hemiptera, Cicadellidae) and Miridae in NY (ARSEF 2020).

**[50] *Pandora dipterigena* (Thaxter) Humber, 1989\***

On Diptera: “small Tipulidae; other small flies or gnats belonging especially to the Mycetophilidae” in MA, ME, NC, and NH (US) (Thaxter 1888), unknown

dipterans in ME and NY (US) (ARSEF 2020), and nematocerans in Mich. (Mexico) (Remaudière and Latgé 1985).

**[51] *Pandora echinospora* (Thaxter) Humber, 1989**

On *Minettia duplicata* (Diptera, Lauxaniidae) and ‘rarely other smaller Diptera’ in ME, NH, and NC (US) (Thaxter 1888).

**[52] *Pandora formicae* (Humber & Bałazy) Humber, 1989**

On Formicinae (Hymenoptera, Formicidae) in ME (US) (R.A. Humber pers. comm.).

**[53] *Pandora gammae* J. Weiser ex. Humber, 1989**

On noctuid larvae (Lepidoptera): *Chrysodeixis includens* in AL and GA (US) in GA (US) and Tamps (Mexico) and *Trichoplusia ni* in AL (US) and Coah (Mexico) (Harper and Carner 1973; Newman and Carner 1975; Gilreath et al. 1986; Sanchez-Peña 1990, 2000). Also on *Mocis* sp. in NL and Coah (Mexico) (S.R. Sanchez-Peña unpubl. data).

**[54] *Pandora gastropachae* (Racib.) Hajek & Gryganskyi, 2024\***

In hardwood forests on *Malacosoma disstria* (Lepidoptera, Lasiocampidae), ranging from BC to QC (Canada) and ME to FL and AL (US) (Filotas et al. 2003).

**[55] *Pandora gloeospora* (Vuillemin) Humber, 1989\***

On *Lycoriella mali* (Diptera, Sciaridae) in mushroom production facilities in MD, DE, and southeastern PA (US) (Miller and Keil 1990, AP Gryganskyi pers. comm.) and cadavers producing conidia found on oyster mushrooms (*Pleurotus* sp.) in FL (US) (MW Miller pers. comm.).

**[56] *Pandora heteropterae* (Bałazy) S. Keller, 2005\***

On *Lygus lineolaris* (Hemiptera, Miridae) in AR (US) (Hannam and Steinkraus 2010).

**[57] *Pandora ithacensis* (Kramer) Hajek & Gryganskyi, 2024\***

On Diptera: *Symporomyia hirta* and *Rhagio mystaceus* (Rhagionidae) and *Empis obesa* (Empididae) in NY (US) (Kramer 1981a) and an unidentified rhagionid in PA (US) (C. Tkaczuk unpubl. data).

**[58] *Pandora montana* (Thaxter) Hajek & Gryganskyi, 2024**

On Diptera on the alpine summit of Mt. Washington, NH (US), infecting “minute gnats, apparently *Chironomus* sp.” (Thaxter 1888).

**[59] *Pandora muscivora* (J. Schröt.) S. Keller, 2005**

On *Syrphus* sp. (Diptera, Syrphidae) in ME (US) (MyCoPortal 2024).

**[60] *Pandora neoaphidis* (Remaud. & Hennebert) Humber, 1989\***

On diverse aphids (Hemiptera, Aphididae) across the US, Mexico, and QC (Canada). In addition, single records of *Lygus* sp. (Hemiptera, Miridae) in NY (US) (ARSEF 2020) and *Aeneolamia albofasciata* (Hemiptera, Cercopidae) in Mexico (Remaudière and Latgé 1985) (Table 10). These last records of this fungus on spittlebugs and mirids should be reconsidered due to the unambiguous nature of this fungus as a specialized aphid pathogen, and the brief and rather incomplete description in these records.

**Table 10.** Recorded arthropod hosts of *Pandora neoaphidis* in the US, Canada, and Mexico, all hosts in the order Hemiptera.

Host Family	Host Species	Country	States/ Provinces	References
Aphididae	<i>Acyrtosiphon kondoi</i>	US	CA	Pickering and Gutierrez 1991
	<i>Acyrtosiphon pisum</i>	US	CA, GA, ID, IL, MN, NY, PA, WA	Folsom 1909; Pickering et al. 1989; Pickering and Gutierrez 1991; ARSEF 2020; C. Tkaczuk unpubl. data
	<i>Acyrtosiphon pisum</i>	Mex	-	Remaudière and Latgé 1985
	<i>Aphis asclepiadis</i>	Mex	-	Remaudière and Latgé 1985
	<i>Aphis coreopsisdis</i>	Mex	-	Remaudière and Latgé 1985
	<i>Aphis fabae</i>	US	WA	ARSEF 2020
	<i>Aphis fabae</i>	Mex	-	Remaudière and Latgé 1985
	<i>Aphis glycines</i>	US	NY	ARSEF 2020; Nielsen and Hajek 2005
	<i>Aphis gossypii</i>	Mex	-	Remaudière and Latgé 1985
	<i>Aphis lugentis</i>	Mex	-	Remaudière and Latgé 1985
	<i>Aphis solitaria</i>	Mex	-	Remaudière and Latgé 1985
	<i>Aphis</i> sp.	Can	QC	ARSEF 2020
	<i>Aphis</i> sp.	US	WA	ARSEF 2020
	<i>Aphis spiraecola</i>	Mex	-	Remaudière and Latgé 1985
	<i>Aulacorthum solani</i>	US	ME	Shands et al. 1972
	<i>Brachycaudus helichrysi</i>	Mex	-	Remaudière and Latgé 1985
	<i>Brachyunguis tetrapteralis</i>	Mex	-	Remaudière and Latgé 1985
	<i>Brevicoryne brassicae</i>	Mex	-	Remaudière and Latgé 1985
	<i>Capitophorus elaeagni</i>	Mex	-	Remaudière and Latgé 1985
	<i>Capitophorus shepherdiae</i>	Mex	-	Remaudière and Latgé 1985
	<i>Capitophorus xanthii</i>	Mex	-	Remaudière and Latgé 1985
	<i>Cavariella hendersoni</i>	Mex	-	Remaudière and Latgé 1985
	<i>Diuraphis noxia</i>	US	CO, ID	ARSEF 2020; Feng et al. 1990
	<i>Hayhurstia atriplicis</i>	Mex	-	Remaudière and Latgé 1985
	<i>Hyperomyzus lactucae</i>	Mex	-	Remaudière and Latgé 1985
	<i>Hyperomyzus</i> sp.	Mex	-	Remaudière and Latgé 1985
	<i>Illinoia</i> sp.	Mex	-	Remaudière and Latgé 1985
	<i>Impatientinum americanum</i>	Mex	-	Remaudière and Latgé 1985
	<i>Macrosiphum euphorbiae</i>	US	FL, ID, ME	ARSEF 2020; Feng et al. 1990
	<i>Macrosiphum</i> spp.	Mex	-	Remaudière and Latgé 1985
	<i>Melanaphis sacchari</i>	Mex	Coah	ARSEF 2020
	<i>Metopolophium dirhodum</i>	US	ID, MT	ARSEF 2020; Feng et al. 1990, 1991
	<i>Myzus ornatus</i>	Mex	-	Remaudière and Latgé 1985
	<i>Myzus persicae</i>	US	AR, ID, ME, VA, WA	Harris 1948; Elkassabany et al. 1992; Kish et al. 1994; Dara and Semtner 2001
	<i>Myzus persicae</i>	Mex	-	Remaudière and Latgé 1985

Host Family	Host Species	Country	States/ Provinces	References
Aphididae	<i>Myzus persicae nicotianae</i>	US	KY, VA	ARSEF 2020; Dara and Semtner 2001
	<i>Rhopalosiphum padi</i>	US	ID	Feng et al. 1990
	<i>Rhodobium porosum</i>	Mex	-	Remaudière and Latgé 1985
	<i>Rhopalosiphum maidis</i>	US	ID, MT	Feng et al. 1990, 1991
	<i>Rhopalosiphum maidis</i>	Mex	-	Remaudière and Latgé 1985
	<i>Rhopalosiphum padi</i>	Mex	-	Remaudière and Latgé 1985
	<i>Rhopalosiphum sp.</i>	Mex	-	Remaudière and Latgé 1985
	<i>Schizaphis graminum</i>	US	ID	ARSEF 2020; Feng et al. 1990
	<i>Schizaphis graminum</i>	Mex	-	Remaudière and Latgé 1985
	<i>Sibobion avenae</i>	US	ID	Feng et al. 1990
	<i>Sitobion sp.</i>	Mex	-	Remaudière and Latgé 1985
	<i>Uroleucon ambrosiae</i>	Mex	-	Remaudière and Latgé 1985
	<i>Uroleucon sonchi</i>	Mex	-	Remaudière and Latgé 1985
	<i>Uroleucon sp.</i>	Can	QC	FPMI 1990
	<i>Uroleucon sp.</i>	Mex	-	Remaudière and Latgé 1985
Cercopidae	<i>Utamphorophora crataegi</i>	Mex	-	Remaudière and Latgé 1985
	<i>Wahlgreniella arbuti</i>	Mex	-	Remaudière and Latgé 1985
Miridae	<i>Aenolamia albofasciata</i>	Mex	-	Remaudière and Latgé 1985
Miridae	<i>Lygus sp.</i>	US	NY	ARSEF 2020

**[61] *Pandora nouri* (Remaud. & Hennebert) Humber, 1989\***

On aphids (Hemiptera: Aphididae) on potato in ME (US) (ARSEF 2020).

**[62] *Pandora pieris* (Z.Z. Li & Humber) Hajek & Gryganskyi, 2024\***

On larvae of *Pieris rapae* (Lepidoptera, Pieridae) in NY (US) (Li and Humber 1984).

**[63] *Pandora sylvestris* Hajek & Gryganskyi, 2024**

On larvae of *Lophocampa caryae* (Lepidoptera, Erebidae) from MI and VT (US) (Hajek et al. 2024a).

**[64] *Pandora virescens* (Thaxter) Hajek & Gryganskyi, 2024**

On Noctuidae (Lepidoptera): *Mythimna unipuncta* in AR (US), *Dargida procinctus* in OR (US), and *Ochropleura fennica* in ON (Canada) (Steinkraus et al. 1993b).

**[65] *Pandora vomitoriae* (Rozsypal) Hajek & Gryganskyi, 2024**

On adult Calliphoridae (Diptera): 'blue bottle flies' in Coah. (Mexico) (Sanchez-Peña 2000) and *Lucilia sericata* in NY (US) (B. Lovett unpubl. data).

***Zoophthora***

**[66] *Zoophthora aphrophorae* (Rostr.) S. Keller, 2007**

On the pine spittlebug, *Aphrophora parallelula* (Hemiptera, Aphrophoridae), in PA (US) (Knoll 1932).

**[67] *Zoophthora canadensis* (MacLeod, Tyrrell & Soper) Remaud. & Hennebert, 1980**

On *Schizolachnus piniradiatae* (Hemiptera, Aphididae) in red pine plantations in ON (Canada) (MacLeod et al. 1979).

**[68] *Zoophthora forficulae* (Giard) A. Batko, 1964**

On *Forficula auricularia* (Dermaptera, Forficulidae) in OR and WA (US) (Rockwood 1950; Hutchison 1963).

**[69] *Zoophthora geometralis* (Thaxter) A. Batko, 1964**

On adults of *Eupithecia* sp., *Petrophora* sp., and *Thera* sp. (Lepidoptera, Geometridae) in ME (US) (Thaxter 1888).

**[70] *Zoophthora ichneumonis* Bałazy, 1993**

On an adult ichneumonid (Hymenoptera) in PA (US) (C. Tkaczuk, unpubl. data).

**[71] *Zoophthora independentia* A.E. Hajek, Humber & Gryganskyi, 2016**

Resting spore stages occurred within adult *Tipula submaculata* (Diptera, Tipulidae) in NY (US) (Hajek et al. 2016).

**[72] *Zoophthora occidentalis* (Thaxter) A. Batko, 1964\***

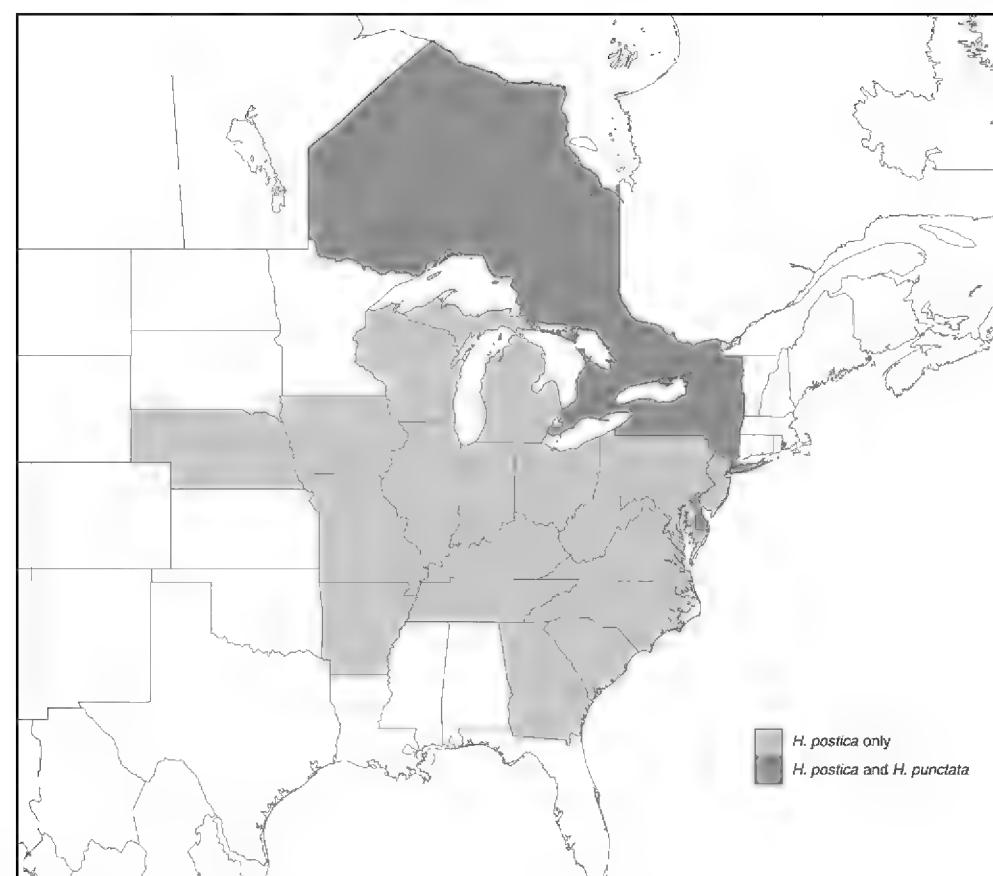
First reported on 'aphides on *Betula populifera*' in MA and ME (US) (Thaxter 1888). On aphids (Hemiptera, Aphididae), *Myzus persicae*, *Macrosiphum euphorbiae*, and *Aphis fabae* in ME (US); *Acyrtosiphon pisum* and *Aphis glycines* in NY (US); and *Sitobion avenae* in ID (US) (Feng et al. 1990; Nielsen and Hajek 2005; Barta and Cagán 2006; ARSEF 2020).

**[73] *Zoophthora phalloides* A. Batko, 1966**

Aphid pathogens (Hemiptera, Aphididae) on *Macrosiphum euphorbiae*, *Nearctaphis bakeri*, *Uroleucon* sp., and *Acyrtosiphon pisum* in QC (Canada), ME and NH (US) (Remaudiére et al. 1978). On *A. pisum* in Oax. (Mexico) and *Theroaphis maculata* in Mexico (ARSEF 2020) and NY (US) (Milner and Soper 1981).

**[74] *Zoophthora phytonomi* (Arthur) A. Batko, 1964\***

Two genotypes infecting weevils in the genus *Hypera* (Coleoptera, Curculionidae) occur in North America (Hajek et al. 1995). The genotype principally infecting *Hypera postica* was first found in 1973 in ON (Canada) and subsequently in 21 eastern US states (Fig. 4). This genotype was also reported in *H. punctata* from NY (US). The second genotype infected *Hypera punctata* in ON (Canada) and NY and DE (US) (Hajek et al. 1995).



**Figure 4.** Distribution of recorded occurrences of *Zoophthora phytonomi* in the US and Canada (Hajek et al. 1995). Dark gray = states and provinces where this pathogen was reported from both *Hypera postica* and *Hypera phytonomi*; light gray = US states where this pathogen was only reported from *H. postica* (Hajek et al. 1995).

#### [75] *Zoophthora porteri* (R.S. Soper) A.E. Hajek, Humber & Gryganskyi, 2016

Resting spore stages occurred within adult *Tipula colei* (Diptera, Tipulidae) in TN (US) (Hajek et al. 2016).

#### [76] *Zoophthora radicans* (Bref.) A. Batko, 1964\*

On hosts in diverse families across Hemiptera, Lepidoptera, Hymenoptera, and Diptera. Widespread distribution across the US, Canada, and Mexico (Table 11).

**Table 11.** Recorded arthropod hosts of *Zoophthora radicans* in the US, Canada, and Mexico.

Host Order	Host Family	Host Species	Country	States/ Provinces	References
Diptera	Drosophilidae	-	US	FL	ARSEF 2020
	Nematocera	-	Mex	Dgo	Remaudière and Latgé 1985
	Tipulidae	-	US	ME	FPMI 1990
Hemiptera	Aphididae	<i>Acyrtosiphon pisum</i>	US	GA	Pickering et al. 1989
		<i>Aphis nasturtii</i>	US	ME	Shands et al. 1972
		<i>Macrosiphum euphorbiae</i>	US	ME	Shands et al. 1962
		<i>Metopolophium dirhodum</i>	US	ID, MT	Feng et al. 1990
		<i>Myzus ornatus</i>	Mex	-	Remaudière and Latgé 1985
		<i>Sitobion avenae</i>	US	ID	Feng et al. 1990
		<i>Theroaphis maculata</i>	US	NY	ARSEF 2020
		<i>Theroaphis maculata</i>	Mex	CDMX	FPMI 1990
		<i>Theroaphis trifolii</i>	Mex	CDMX	Remaudière and Latgé 1985
	Cicadellidae	<i>Empoasca fabae</i>	US	IL, MI, NY, WI	ARSEF 2020; McGuire et al. 1987
	Pentatomidae	<i>Bagrada hilaris</i>	Mex	Coah	Torres-Acosta et al. 2016
Psyllidae		<i>Trioza</i> sp.	Can	QC	ARSEF 2020
		<i>Psylla trimaculata</i>	Can	QC	FPMI 1990
		<i>Cacopsylla mali</i>	Can	NS	Gilliatt 1925
Triozidae	<i>Bactericera cockerelli</i>	Mex	Coah		Torres-Acosta et al. 2016

Host Order	Host Family	Host Species	Country	States/ Provinces	References
Hymenoptera	-	-	US	ME	ARSEF 2020
	Diprionidae	<i>Neodiprion tsugae</i>	US	AK	ARSEF 2020
Lepidoptera	Geometridae	<i>Lambdina fiscellaria</i>	Can	NF	Otvos et al. 1973
	Hesperiidae	<i>Thymelicus lineola</i>	Can	QC	FPMI 1990
	Noctuidae	<i>Autographa precationis</i>	US	IN	Yendol and Paschke 1987
		<i>Rachiplusia ou</i>	US	IN	Yendol and Paschke 1987
		<i>Trichoplusia ni</i>	US	IN	Yendol and Paschke 1987
		<i>Trichoplusia ni</i>	Mex	Coah	Sanchez-Peña 2000
	Plutellidae	<i>Plutella xylostella</i>	Mex	Gto	ARSEF 2020
Tortricidae	Acleris variana	US	ME		ARSEF 2020
	Acleris variana	Can	NF		FPMI 1990
	<i>Archips argyropila</i>	US	PA		Knull 1932
	<i>Choristoneura biennalis</i>	Can	BC		FPMI 1990
	<i>Choristoneura fumiferana</i>	US	ME		Vandenberg and Soper 1975
	<i>Choristoneura fumiferana</i>	Can	BC, NS, ON		FPMI 1990
	<i>Rhopobota naevana</i>	US	MA		Sawyer 1933

### [77] *Zoophthora rhagonycharum* (Bałazy) S. Keller, 2007

Resting spore stages in adult *Rhagonycha vilis* and *Rhagonycha fraxini* (Coleoptera, Cantharidae) in NY (US) (Hajek et al. 2024b).

### **Strongwellsea**

#### [78] *Strongwellsea castrans* A. Batko & Weiser, 1965

On *Delia platura* (Diptera, Anthomyiidae) in WI (US) (Strong et al. 1960) and *Delia radicum* in ON (Canada) (Nair and McEwen 1973).

#### [79] *Strongwellsea magna* Humber, 1976

On *Fannia canicularis* (Diptera, Fanniidae) in CA (US) (Humber 1976).

### **FORM GENUS**

#### **Tarichium**

#### [80] *Tarichium megaspermum* Cohn, 1875

On two species of Noctuidae (Lepidoptera): *Euxoa messoria* and *Euxoa ochrogaster* in BC and ON (Canada) (Bucher and MacLeod 1974; Steinkraus et al. 1993b).

### **Incomplete and questionable records**

For some species we could not resolve the identification of the fungal species, especially older identifications based only on morphology or species for which confusion exists regarding the correct fungal species name to use. For example, the species *Entomophthora carpentieri*, named by Giard in 1888 from only resting spores collected in Europe, was identified by V.K. Charles from *Horistonotus uhleri* (Coleoptera, Elateridae) collected in 1934 by J.N. Tenhet in SC (My-

CoPortal 2024). However, this fungal species is considered questionable by Keller (1991) and Bałazy (1993), and any potential synonymous species are not known in North America, and so it has not been included in this checklist.

One isolate of *Entomophaga conglomerata* is listed in the ARSEF culture collection (ARSEF 2020), but a recent publication demonstrated that this isolate instead belongs in the genus *Batkoia* (Gryganskyi et al. 2022b), and therefore this example was not included. Tipulids in NHand NC (US), collected by Thaxter, harbored a fungus named *Entomophthora thaxteri* (MacLeod and Müller-Kögler 1973), but this species was not adequately described. However, trying to find the correct genus and species for this species has been difficult. Over time, it has been suggested that this species could be *E. conglomerata*, *Entomophaga tipulae*, or *Entomophthora tipulae* (MacLeod and Müller-Kögler 1973; Bałazy 1993). In addition, because Thaxter found only resting spores in adults, perhaps this is *Zoophthora independentia* or *Z. porteri*. Therefore, this species (whatever it is) is not included in the checklist. In the case of *Pandora blissi*, this genus name is provided as *nomen dubium*; the native host of this species is no longer as abundant as in the past (Waldbauer 2005), and studies are currently underway to obtain specimens so the correct genus can be determined.

Sometimes, pathogen/host associations seem incorrect in initial reports. For example, in 1909, *Zoophthora radicans* was reported infecting the weevil *Hypera punctata* in IL (US) (Folsom 1909). However, now we know that *Zoophthora phytonomi* (not described until 1964) infects this weevil species in other regions (Fig. 4), and we have no examples of *Z. radicans* infecting Coleoptera (see Table 11). In this case, we have not included this location information under *Z. phytonomi* (Fig. 4) or under *Z. radicans* (Table 11).

Finally, as we do not include entries for which a species name has not been provided. Thus, we could not include an unidentified species infecting the economically important northern corn rootworm, *Diabrotica barberi* (Naranjo and Steinkraus 1988); in this case beetle cadavers only contained resting spores. We also could not include the only example from the Arctic. *Zoophthora* sp. was reported causing epizootics in outbreak populations of the noctuid *Eurois occulta* in West Greenland (Avery and Post 2013). The larval cadavers that had summited on the vegetation only contained resting spores, and the species could not be identified or described at that time.

## Discussion

In 1963, a checklist of entomophthoralean fungi from the Western Hemisphere listed 39 species, all ascribed to the same genus: *Entomophthora* (Hutchison 1963). Today, with increased collection data and the incorporation of taxonomic changes within this group, our survey of arthropod pathogens in the Entomophthoromycotina found in North America includes 80 species in 14 genera, within 2 classes, plus one species in a form genus. A recent checklist of all fungi in North America (Bates and Miller 2018) lists only 38 arthropod-pathogenic species belonging to the Entomophthoromycotina. This checklist most likely relied on the Hutchison (1963) checklist, as it was the most recent available checklist for this group (Hutchison, 1963), underscoring the necessity for an updated checklist of Entomophthoromycotina in North America.

In their checklist for all North American fungi, Bates and Miller (2018) discuss the issue that there are many instances where European names were initially assigned to North American taxa based on morphological similarities. However, North American strains could represent cryptic taxa native to this continent that should be described as separate species, particularly if supported by molecular findings. We assume that this type of work will be undertaken in the future. However, at present many species in this group have not been isolated *in vitro* and/or there are no herbarium samples that can be used for DNA extraction. Therefore, to move forward along these molecular lines, in many cases, new specimens must be collected for analyses.

In fact, many species of arthropod pathogenic Entomophthoromycotina found worldwide have not been isolated in culture, and sequences are not available for molecular identification. In nature, viable cells of these fungi are quite ephemeral, and it is therefore difficult to collect them for isolation. The exception to this would be cadavers bearing resting spores (azygospores or zygospores). However, resting spores are often not found or, if found, are dormant and difficult to either germinate or use for DNA extraction (but see Bidochka et al. 1995; Eilenberg and Jensen 2018; Hajek et al. 2018). The ARSEF collection has North American cultures or samples from 29 of the species included in this checklist (approximately 36%). We hope that this annotated checklist will make it more possible in the future for the culture and sequencing of additional species in North America.

Taxonomic changes in this group have been relatively frequent since the first publication on species of Entomophthoromycotina in the United States by Thaxter in 1888, referring to this group as the Entomophthoreae. These taxonomic changes pose challenges for understanding whether names for host/fungus associations in the older literature are accurate today. For example, *E. muscae* is now known to be a species complex (Elya and De Fine Licht 2021), with one species named *E. muscae* s.s delimited within the complex. Therefore, for older records when *E. muscae* is mentioned, it is unclear which of the species in the complex is being discussed and how to apply historical findings to the modern circumscription of the species *E. muscae* itself. Therefore, since this checklist treats the three species of this species complex known from North America separately, the older reports of *E. muscae* have usually not been included in order not to introduce errors. The *Entomophaga grylli* species complex raised similar problems. Today, two members of this complex occur in North America, and older literature did not differentiate between them, with the result that older reports for collection locations could not be included.

Likewise, confusion has occurred with *Pandora neoaphidis*, for which the correct nomenclature was only resolved in 1980 (Barta and Cagán 2006). From 1888 (Thaxter) until 1980, in North America, *P. neoaphidis* was incorrectly known as *Empusa aphidis* and later *Entomophthora aphidis*. However, in 1980 *Entomophthora aphidis* was synonymized with *Zoophthora aphidis*, a species known only from relatively few host aphids in western and central Europe. We assume that records of *Empusa* or *Entomophthora aphidis* in North America before 1980 probably refer to *P. neoaphidis*, especially for collections from Maine, due to the common occurrence of *E. aphidis* and the presence of cultures of *P. neoaphidis* from Maine collected in 1972 and 1977 in the ARSEF collection (ARSEF 2020).

Our records of the distribution of fungal species are predominantly based on reports in the literature. The time of year, or even year of collection, is not always reported. Additionally, entomophthoralean fungi have been collected by only a handful of experts and remain vastly understudied across many locations in North America. Therefore, if a state or province is not listed, this is not definitive proof that a species is not present there, but rather this suggests that further surveys are necessary.

This annotated checklist provides data on these arthropod pathogens by connecting arthropod host species and fungal species at different locations within North America. Therefore, for each record, three specific pieces of information were needed: 1) host species, 2) fungal species, and 3) collection location. Unfortunately, some publications (although relatively few) did not provide separate data for these three metadata types and thus could not be included. Such problems arose with Remaudière et al. (1978), where all fungal pathogens and their aphid hosts were merged for one trip covering NH (US), and ON and QC (Canada). Similarly, we could not include data from Feng et al. (1990), in which data from collections of three species of aphid-pathogenic *Conidiobolus* species were merged so that locations and hosts of individual species were not listed (one of these species is now a *Batkoia*), or from Wraight et al. (1993), in which data for fungal infections of several cereal aphid species were merged.

## Conclusion

In conclusion, we provide an updated checklist of arthropod pathogenic fungi in the Entomophthoromycotina detected in North America, using the latest taxonomy and largely based on published literature. While this checklist includes many more species than the last checklist (Hutchison 1963), there are still many arthropod-pathogenic species known from this subphylum (see Sacco and Hajek 2023) that have not been found in North America. Additional sampling is needed to determine if these are truly absent from the continent or await discovery as well as whether new discoveries await. Additionally, given the paucity of molecular data (De Fine Licht et al. 2016), sequencing of additional species from verified specimens, together with improved taxonomies, is an area of future research that will enhance DNA-based identification of these fungi. This updated checklist provides a framework for future efforts sampling and documenting the biodiversity of this important, yet understudied, group of fungi.

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## Additional information

### Conflict of interest

The authors have declared that no competing interests exist.

### Ethical statement

No ethical statement was reported.

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### Author contributions

Conceptualization: A EH. Data curation: A EH, K LS, C T, S SP. Formal analysis: A EH. Funding acquisition: K EB. Investigation: A EH, S SP, C T. Methodology: A EH. Project administration: A EH. Software: B L, K LS. Supervision: K EB, A EH. Validation: A EH. Visualization: K LS, B L. Writing - original draft: A EH. Writing - review and editing: C T, S SP, K LS, A EH, B L, K EB.

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### Data availability

All of the data that support the findings of this study are available in the main text.

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